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IMPACT BEHAVIOURS OF BIO-INSPIRED SANDWICH BEAM UNDER CONTINUOUS IMPACTS

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Masters	
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Name : Tan Juin Hwee

Matric No. : 58070

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10th August 2020

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(Associate Professor Dr. Ahmad Kueh Beng Hong) Date

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ABSTRACT

Impact behaviours of newly designed bio-inspired sandwich beam (BHSB) inspired by the woodpecker's head configuration were numerically examined under continuous low-velocity impact loadings. The newly designed beam contains four main layers, in which carbon fiber reinforced plastic top and bottom skins were employed in sandwiching dual-core consisting of solid hot melt adhesive (HMA) and aluminium honeycomb materials. Innovatively, the solid HMA core was designed in an arch shape. The impact behaviours of the BHSB have been numerically examined by using the finite element software, ABAQUS. Impact loadings were performed in a repeated manner with a hemisphere steel impactor for three impact energy levels of 7.28J, 9.74J, and 12.63J. In all cases, stresses were observed to be mainly concentrated on the impact region while some stresses were distributed to the supports. The new BHSB can resist up to 5 continual impacts at both impact energies of 7.28J and 9.74J but only up to 3 times repeated loads for 12.63J. Besides, impact resistance efficiency index, which assessed the overall impact performance of the sandwich structures, were compared between the newly designed BHSB and the previously designed BHSB. The impact resistance efficiency indices of the newly designed BHSB were found to be 1.31-5.33 times higher, exhibiting an improvement in performance.

ABSTRAK

Tingkah laku impak "bio-inspired sandwich beam" (BHSB) yang baru direka yang diilhami oleh konfigurasi kepala pelatuk kayu diperiksa secara berangka di bawah beban hentaman berkelajuan rendah berterusan. Rasuk yang baru direka mengandungi empat lapisan utama, di mana kulit atas dan bawah "carbon fiber reinforced plastic" digunakan dalam sandwic dual-core yang terdiri daripada "solid hot melt adhesive" (HMA) dan "aluminium honeycomb". Secara inovatif, teras HMA padat direka bentuk dalam bentuk lengkungan. Tingkah laku impak BHSB telah diperiksa secara berangka dengan menggunakan ABAQUS. Beban hentaman dilakukan secara berulang dengan pemukul keluli hemisfera untuk tiga tahap tenaga hentaman 7.28J, 9.74J, dan 12.63J. Dalam semua kes, tekanan diperhatikan terutama tertumpu pada kawasan hentaman sementara beberapa tekanan disalurkan ke sokongan. BHSB baru direka dapat menahan hingga 5 hentaman berterusan pada kedua-dua tenaga hentaman 7.28J dan 9.74J tetapi hanya 3 kali beban berulang untuk 12.63J. Selain itu, indeks kecekapan ketahanan hentaman, yang menilai keseluruhan prestasi hentaman struktur sandwic, dibandingkan antara BHSB yang baru direka dan BHSB yang direka sebelumnya. Indeks kecekapan ketahanan hentaman BHSB yang baru dirancang didapati 1.31-5.33 kali lebih tinggi, menunjukkan peningkatan prestasi.

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LIST OF SYMBOLS

σ_f - Global longitudinal strength of skin material

σ_c - Core compressive strength

τ_c - Core shear strength

I_e - Impact resistance efficiency index

E_{abs} - Absorbed energy

F_{max} - Maximum contact force

A_d - Damage area

g - Gravitational acceleration

m_b - Mass of sandwich beam

t - Thickness of sandwich beam

σ_{max} - Maximum stress in sandwich beam

CHAPTER 1

INTRODUCTION

1.1 Introduction

Chai and Zhu (2011) defined that composite sandwich panel is made up of two stiff and thin skins with a lightweight, thick and low modulus core. This composite sandwich structure has a high value of the strength/weight ratio. It is not only relatively lightweight however it can support transverse loads more efficiently. Usage of sandwich structures are commonly found in many engineering application such as marine and transport industries, aerospace and aircraft industries.

According to Chai and Zhu (2011), it has been widely examined the impact loads exerted on the composite sandwich panels by using of experimental techniques, mathematical modelling and also numerical methods. As composite sandwich structures are widely applied in engineering application and they are prone to failure due to impact load, there are some areas of research are still interesting being pursued such as contact analysis between the impactor and the composite surfaces, the response of structure after impact, the failure mechanism by impact, the residual property after impact, high-velocity impact analysis and impact analysis of soft body impactor.

Abo Sabah et al. (2019) stated some failure models of sandwich beams during the low-velocity impact test such as face wrinkle, face yield, indentation and core failure. According to Abrate (1998), core buckling, delamination in the impacted face sheet, core cracking, matrix cracking and fibre breakage in the facings have been identified as the failure modes of sandwich beams. In general, beam's geometry and properties of the materials for skin layer and core layer can affect the type of failures. Damages are usually existed on the top layer of structure only as low-velocity impact does not lead to perforation to the structure whereas minor damage and core shearing are involved in the bottom layer of structure. Face yielding is meant by the surface of structure that undergoes fracture completely due to micro-tension. Besides that, face wrinkling is meant by the skin that undergoes some matrix cracking and fibre breakage as micro-compression without the occurrence of fracture.

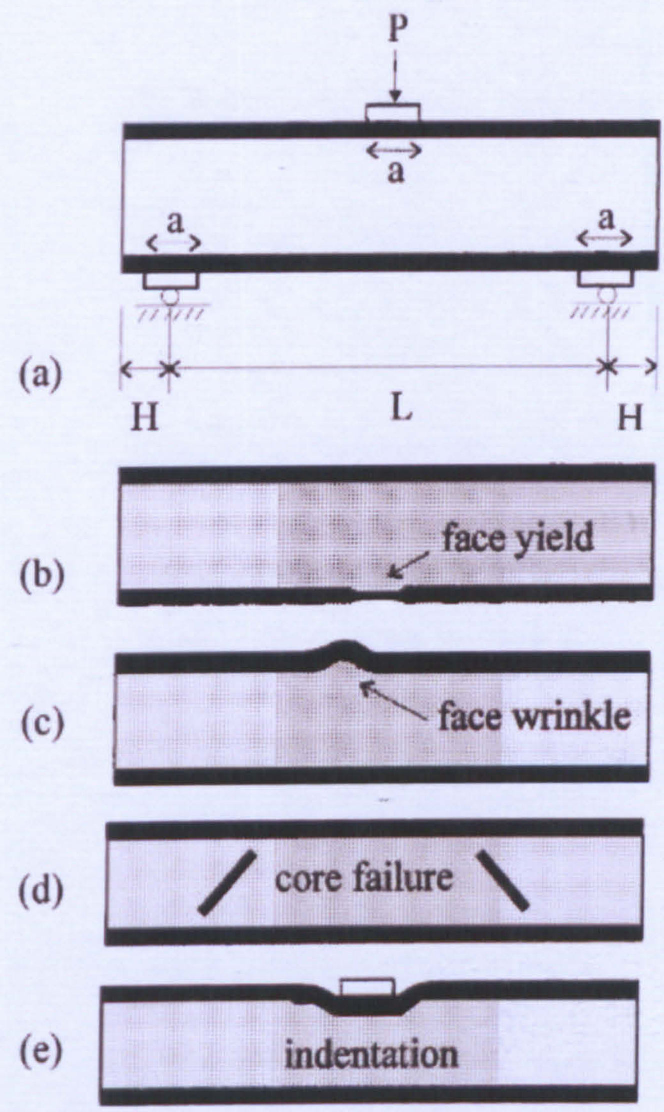

Figure 1.1. Failure modes of sandwich beams: (a) loading configuration, (b) face yielding, (c) face wrinkling, (d) core yielding and (e) indentation (McCormack et al.,

Figure 1.2 shows that failure of glass fibre reinforced polypropylene (GFPP) sandwich structures with 10 mm thick closed cell aluminium foam block subjected to impact energies. From the figure 1.2, it can be clearly found that it is very dangerous when continuous impact energies exerted on the sandwich structures. If such failure occurs on the structure built, human safety will being threatened for more severe consequences.

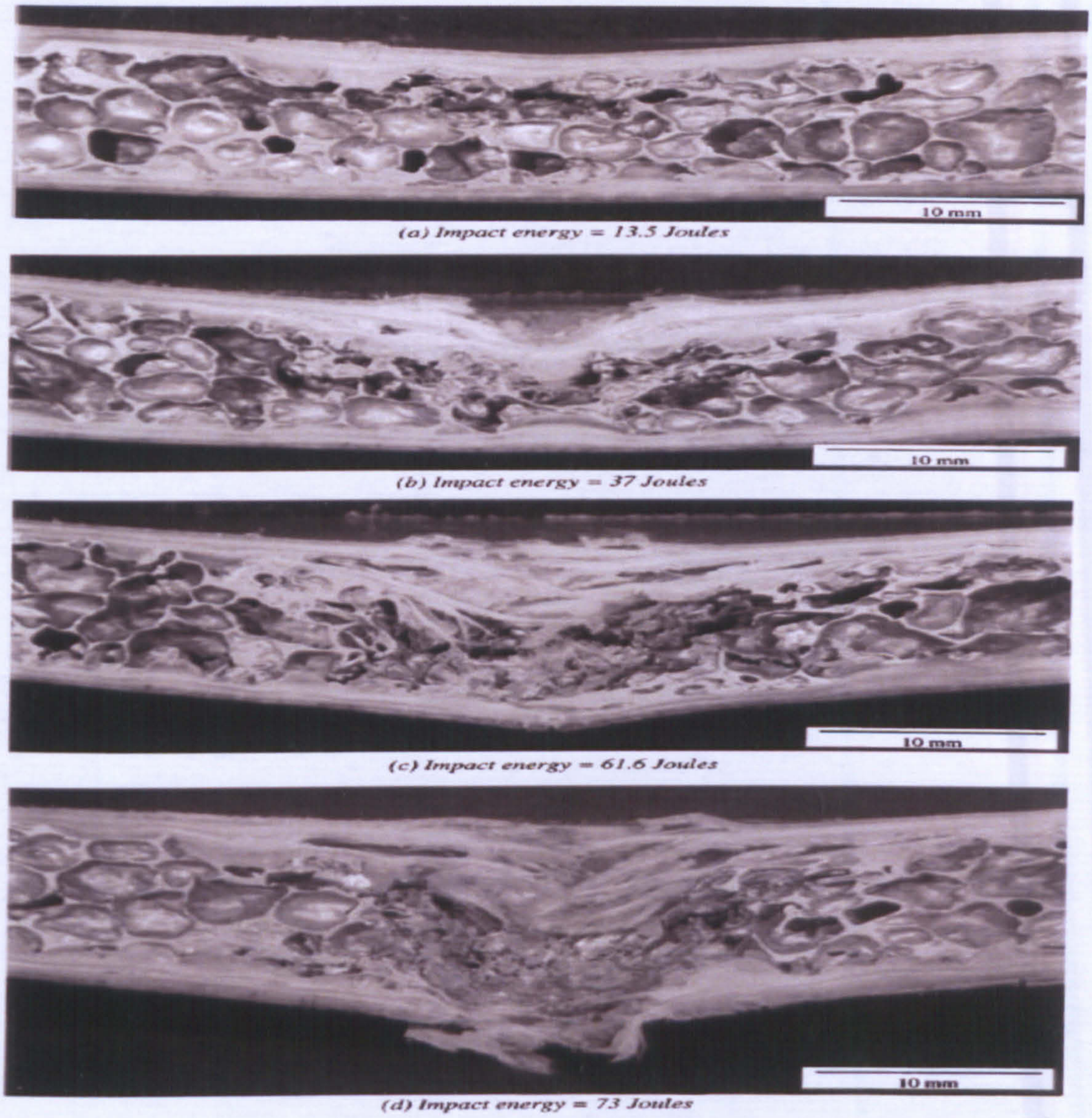

Figure 1.2. Sections of cross-ply GFPP-reinforced aluminium foam sandwich structures subjected to impact energies between 13 J and 73 J (Villanueva & Cantwell, 2004).

1.2 Problem statement

Concept of sandwich construction still remains interesting though composite sandwich structures have been used for non-strength part of structures in the last decade. Due to complexity nature of sandwich structures, the investigation of impact behaviour of composite sandwich beam under different continuous impact energies remains an active research topic. Different impact load conditions can bring a direct risk to the life span of the sandwich structures. More serious consequences can be expected in structurally and also in terms of human safety. The consequences can be more severe if the loading environment is in the presence of impact and blasting.

Past researches had shown that several factors which are stiffness, damping and mass of structure can influenced the impact response of a sandwich structure. A good sandwich structure is not only higher in value of the strength/weight ratio but it should be higher resistance to extreme continuous load magnitude.

From the research works done before, it can be clearly seen that composite sandwich structures are vulnerable to impact-induced damages. Impact behaviour and impact efficiency of sandwich beam with core layer in arch shape is an interesting topic and still not being studied. Impact resistance of sandwich structure is very important to ensure that the structure can last longer and sustain more loadings exerted on it. The inspiration of using core layer in arch shape comes from the cultural of Roman development which they believed arch structures can sustain more loads on it.

Hence, current research work is conducted to investigate the impact behaviour of sandwich beam with the solid hot melt adhesive (HMA) layer in arch shape due to varying continuous impact energies. The main purpose of forming an arch shape for solid HMA layer is inspired by the woodpecker's hyoid structure so that impacted load can be mitigated effectively. Solid HMA layer with an arch shape can transfer the compressive load to the support at two ends effectively because the force exerted are tangential to the end of arch.

1.3 Aim and objectives

The main objectives of the research work are:

i. To develop a composite sandwich beam finite element model under impact loading.
ii. Numerically examine the impact behaviour of the sandwich beam due to varying impact energies.
iii. Compute the impact efficiency of the sandwich beam due to different impact energies.

1.4 Scope of study

i. The sandwich beam is a C-clamp supported at two ends.
ii. There are two cores and one skin material used for the sandwich beam.
iii. The skin material is made of carbon fibre reinforced plastic (CFRP) whereas core materials are made of solid hot melt adhesive (HMA) as core I and aluminium honeycomb as core II.
iv. Three levels of continuous impact energy: 7.28J, 9.74J and 12.63J are applied perpendicularly to centre of the sandwich beam.
v. Dimension of the sandwich beam is 300 mm long, 25 mm wide and 25.4 mm thick.
vi. The stacking sequence of skin is $[0/\mp 30]$.
vii. The model of bio-inspired aluminium honeycomb sandwich beam has the solid HMA core layer in arch shape with angle of 36°.
viii. The finite element software, ABAQUS/CAE 6.13-1, is used for the impact modelling.

1.5 Significance of study

As usage of composite sandwich structures can be commonly found in many engineering application, extensive works have been carried out numerically. It is very complex and having unique behaviour in resisting the impact loading. Hence, the impact behaviour of composite sandwich structure under continuous impact loading was examined in order to improve their performance under services condition.

Solid HMA as the core I of the composite sandwich structure was designed in arch shape with 36° of arch leg which can absorb impact energy efficiently and transfer it to the support safely without damaging the skin layer of the sandwich beam.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter generally discussed on the previous research works on the composite sandwich structure. Important points such as problems considered, method used and main result of previous research work are extracted in details in this chapter.

2.2 Mechanical behaviour of sandwich structures

Mechanical test was carried out by Wang et al. (2010) as only few investigations on the mechanical properties of sandwich structures with carbon fiber-reinforced pyramidal lattice truss core have been carried out. Wang et al. (2010) carried out the compression and shear tests by using the Instron 5569 universal testing machine at the room temperature and displacement rate of 0.5 mm min^{-1} which followed the standards from ASTM C365 and C273.

Four samples are tested in the compressive test. The representative compressive stress-strain is shown in Figure 2.1a. Based on the stress-strain curve, initial linear response is occurred followed by the peak compressive stress. This point is occurred when the failure of the truss member is first to be observed. After that, value of stresses decreases subsequently when strain is increasing with the serrations in the compressive stress vs strain curves. Based on Figure 2.1b, failure mode of the sandwich structures were observed during the compressive test which are splitting and buckling of the truss members.